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SPLINE BASED MESH GENERATOR FOR WIND TURBINE BLADES

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Summary. This paper details the development of a block structured spline based mesh generator for wind turbine blades, developed to streamline the workflow from CAD modeling to simulation and analysis.

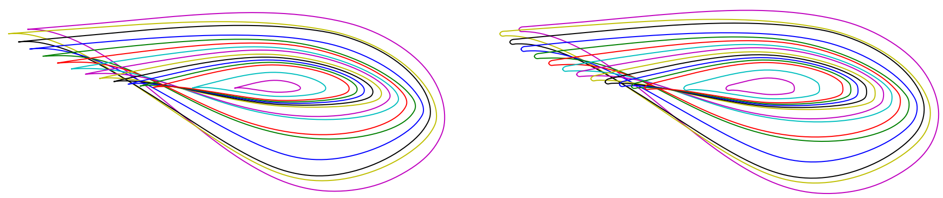
1 INTRODUCTION

Mesh generation involving complex geometries, such as wind turbines, is highly complicated. The problem is generally addressed using tetrahedral meshes, or hybrid meshes with hexahedral elements close to the body and tetrahedral elements elsewhere. The popularity of such mesh generators can be attributed to their associated ease of use and relative automation, which comes at the cost of numerical accuracy in the subsequent analysis. Added to this, such meshes can generally not represent the true geometry. Since 2005, isogeometric analysis which offers an integration of analysis and CAD geometry through the same basis functions is catching up. The method offers demonstrably better accuracy, as well as an exact geometric representation. This method has, since its inception, been applied to solving problems from the domain of fluid and structural mechanics. The availability of NURBS-based surface modeling software such as Rhinoceros has made it possible to create complex geometries with relative ease, but the lack of a volumetric spline-based mesh generator proves to be a bottleneck.

This work presents an automatic block-structured spline-based mesh generator for wind turbine blades. It has been developed initially for the NREL 5MW reference blade, but with a modular approach that will allow it to handle other geometries as well.

2 INPUT SPECIFICATION

The NREL 5MW reference blade[1] is defined in terms of cross-sectional data at 19 points along the blade axis from 2 m to 62.9 m. At each point is defined the airfoil shape, its chord length, the aerodynamic center as well as the twist angle. The innermost airfoils (until about 10 m) are cylindrical, the middle (until about 40 m) are DU (Delft University) airfoils of various kinds, and the outermost are NACA64 airfoils. See Figure 1a.



(a) Sharp trailing edge (b) Exaggerated railing edge modification

Figure 1: Airfoils for the NREL 5MW wind turbine blade.

In order to be able to create an "O"-mesh, we impose a modification to each airfoil to create a rounded trailing edge. This edge is uniformly 1 cm in size across the entire blade, independent of chord length. Relative to the chord length, this modification is between 0.22 % and 1.4 %. See Figure 1b, where the effect has been exaggerated by a factor of five.

3 METHODOLOGY

The whole procedure can be subdivided into two steps: solid modeling or blade construction and volumetric mesh generation. The mesh generation is performed using cubic splines everywhere, and the spline order is then adjusted in the final step before output, to also allow the creation of linear or quadratic models.

3.1 BLADE CONSTRUCTION

Simple cubic interpolation based on the cross sectional data can be used to form the complete blade geometry from the hub at a radius of 2 m to the last cross section at 62.9 m. In practice, the sharp transition from cylindrical cross sections to a narrow trailing edge will cause the wall geometry to intersect with itself. For this reason we employ a two-stage interpolation process in this region. An intermediate grid of sufficiently high resolution is formed with linear interpolation, which can then be refined to the desired final resolution with a higher order interpolator.

To close the tip we lift the central chord of the final cross section to a reasonably modest height (around 20 cm), and form cross section arcs at each node along the length of the airfoil. C^1-continuity can be ensured by conforming to the known normal direction of the blade geometry at the interface. They are then lofted together and subdivided to form a 12-patch structure. See Figure 2.

3.2 VOLUMETRIC MESH GENERATION

At a given set of points along the blade, we wish to create a surrounding "O"-mesh connecting the airfoil to a circle with a given radius, centered at the aerodynamic center. Transfinite interpolation (TFI), also known as the Gordon Hall algorithm[2], is a useful method for "filling in" a surface between four curves or the volume between six surfaces. However, it has two crucial limitations:

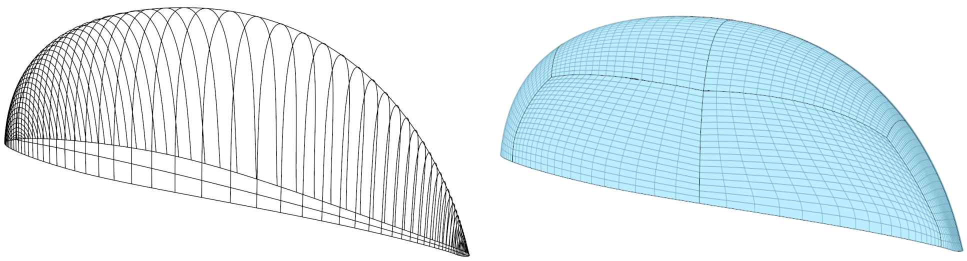
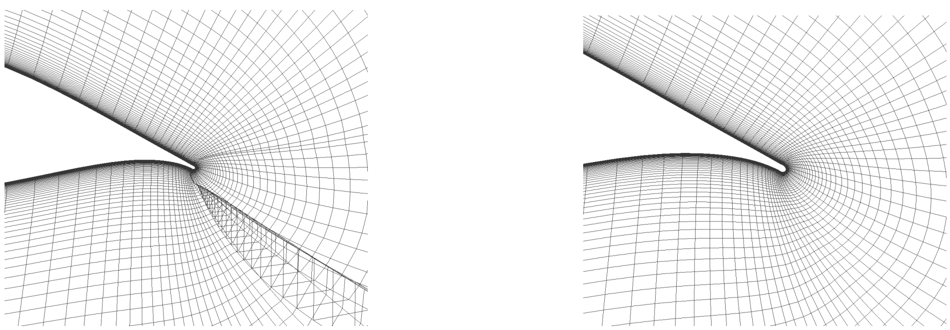


Figure 2: Closing the tip of the blade.



(a) Naive TFI (b) Orthogonalized and smoothed TFI

Figure 3: Fixing the TFI algorithm

- The Jacobian is not guaranteed to be everywhere positive, which means gridlines might intersect. This often happens for nonconvex domains.
- The gridlines close to the body are not guaranteed to be orthogonal, which is important for high Reynolds number CFD.

This causes problems near the trailing edge, as seen in Figure 3a. To mitigate this, we employ an algorithm that "grows" the mesh from the body outwards. At each step, the gridlines are projected some distance in the normal direction, after which a Laplacian smoothing is applied. The final points are given by a weighted average with the ordinary TFI. The weight, and the strength of the smoothing, can be controlled by a coefficient that should be small in the boundary layer and approach one relatively quickly away from it. The final result can be observed in Figure 3b.

Precisely the same algorithm can be applied to the tip of the blade, but here we must deal with all three dimensions simultaneously. First, the tip is connected to the surrounding hemisphere with interpolated curves, which are then filled in using two-dimensional TFI. See Figure 4.

After further subdivision (for purposes of parallelization), the final structure of the mesh might look something like what is illustrated in Figure 5.

4 CONCLUSION AND FUTURE WORK

The mesh generator described in this work can be used to generate spline based meshes for isogeometric analysis. The methodology ensures exact geometric representation and hexahedral

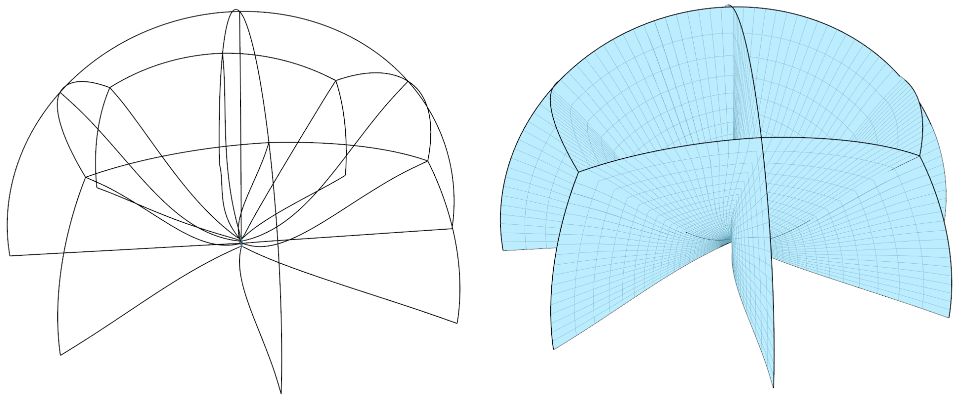


Figure 4: Volumetric mesh for the tip

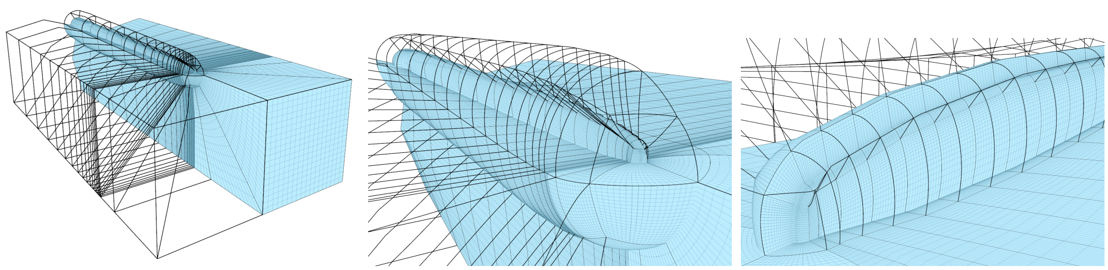


Figure 5: Full mesh structure

elements everywhere. The block structured meshing approach offers more flexibility in optimal load balancing for high performance computing. Currently, the methodology applies to a single blade but work is in progress to extend it to a full turbine containing any number of blades.

5 ACKNOWLEDGEMENT

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REFERENCES

[1] Jonkman, J., Butterfield, S., Musial, W. & Scott, G. Definition of a 5-MW Reference Wind Turbine for Offshore System Development. Tech. Rep. NREL/TP-500-36060, National Renewable Energy Laboratory, Golden, Colorado, USA (2009). URL `http://www.nrel.gov/docs/fy09osti/38060.pdf`.

[2] Gordon, W. J. & Hall, C. A. Construction of curvilinear co-ordinate systems and applications to mesh generation. *International Journal for Numerical Methods in Engineering* **7**, 461–477 (1973).